TYPOLOGY OF SURFACE WIND FIELDS IN BUDAPEST

by
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1. Results of former studies of the wind climate of Budapest

Deeper and deeper knowledge is needed about the processes going on in the boundary layer of the atmosphere, that has been brought in the centre of scientific interest through the needs of practice (e. g. acitivities in regional development and environment protection). The protection and planned improvement of the atmospheric environment in towns and cities urges in Hungary first of all an intensive knowledge of Budapest's climate since one fifth of the population and one third of the country's industry is, concentrated there. In the research of the different climatic elements a special attention must be devoted to the *wind*, the major factor in the transmission of the polluting materials, and one of the basic components of the thermal comfort. Despite of all these, relatively few are the number of studies dealing with the wind in the Hungarian capital. The monograph discussing the climate of Budapest (Probáld, 1974) discusses in detail the energy balance, the phenomenon of heat island and the distribution of precipitation, while it dedicates only a short summary to the airflow patterns of the city, about which our knowledge can not be considered as satisfactory, neither from the point of view of science, nor from that of practical requirements.

It is a generally known fact, that the data about distribution of surface wind are often only of meso- or microclimatic validity (Bacsó, 1959). Since until the establishment of the Observatory in Pestlőrinc (1953), the only anemograph "characterizing the city" was operating in the headquarters of the Meteorological Institute in Kitaibel Pál Street, all the handbooks describing Budapest's climate of winds rely on the data given by that station (Réthly, 1947, Bacsó 1958). The first serious attempt for characterizing the regionally very different airflow conditions was Bacsó's (1959), in his book on the climate of Hungary, by using the data for thirty years of 8 climate registering stations in Budapest. He disclosed the frequency distribution of wind courses, thus illustrating the significant divergencies caused by the physiography and the urban structure within a relatively small area. He pointed out, however, that through the primitive observations with wind vanes the series of data provided by the 8 stations can only give "poor and imperfect characterization" of the wind climate of the city area.

The climate of Budapest is very difficult first of all because of its location on the edge of two main geographic regions; the orographic effect of the Buda Hills and the chain of hills surrounding the Pest plain determine the climate of the capital. On the other hand, one must reckon with the emergence of an "urban-type circulation" directed towards the centre of the densely built up areas. To discover the local circulation caused by the heat island, Péczely (1962) carried out an investigation by using wind registrates from 1955 – 58 at the Pestlőrinc and Kitaibel Pál Street observatories. Péczely concluded that the frequencies of wind directions at the two stations differ from each other a great deal, with the effect of both the urban circulation and the mountain and valley breeze being reflected in it. Péczely also published data on the annual and daily changes of the frequency of the regional circulation caused by the urban heat island.

During the 1960s, as a result of the temporary upswing of the urban climatological research, Fuess-type wind registering instruments were set up first on Madách Square and in Gyáli Street (1964), then in the Zoo and on the Citadel on Gellért Hill (1967). So together with the registering stations set up earlier (Szabadság Hill, Kitaibel Pál Street, Pestlőrinc Observatory, Ferihegy, Budaörs), the number of stations equipped with wind-registering instrument grew to 10. First elaboration of registrates for the first – very short – period was done by Gajzágó (1967). A later study by Bán and Gajzágó (1974) revealed the annual distribution of the frequency of wind courses, decided from daily data at the observatories of Pestlőrinc, Madách square and Gyáli Street. The study also disclosed very valuable facts about the regional differences of the windspeed. According to the Bán and Gajzágó report, the surface wind changes its direction clockwise in untroubled anticyclonal weather during the day, and there is a certain phase-shift between the different stations, which sometimes results in an airflow pattern converging towards the centre of the city. "In the case of Budapest we can not speak about a regularly occurring urban termic wind... The city's heat island may at most only strengthen the mountain and valley breeze at certain places." This is the summary statement of the study by Bán and Gajzágó, reflecting a view significantly different from that of Péczely.

2. A new approach to the mesoclimatic characterization of the wind climate: the typology of stream fields

The material published so far on the wind climate of Budapest – despite of the happy increase in the number of wind registering instruments – have left a number of unsolved problems, and was unable to satisfy the basic data requirements of diffusion climatology. This induced the present study, aimed to describe the city's wind climate from a totally new approach. Our method may be used for revealing the diffusion climatological characteristics at other areas of similar size and physiography, too. The essence of the method is the classification of the wind fields and the determination of the climatic-statistic characteristics of the types. As far as we know the only study somewhat similar to the present one is that by Szepesi and his colleagues (1974), having set up 6 wind registering instruments in the city of Pécs in order to satisfy the informational requirements of their transmission model. The data acquired in this way have been registered on a map, with airflow patterns classified into 29 types. Similar method has been adopted in this paper in order to characterize the wind climate of a larger area of more complicated physiography and supplied with more wind registering instruments. This made it necessary to elaborate the method to very small details and, in many aspects, to develop it further.

The main targets of the study and the considerations founding them are as follows:

2.1. The air pollution of our settlements, on an ever higher degree derives from surface and regional sources; the surface wind field is *the major transmission factor in the micro- and mesoscale pollution processes.* In order to take the adequate steps for the decrease of the emission, and for the preparation of the decisions concerning regional and city planning, it is necessary to characterize the atmospheric environmental conditions of transmission in detail, in a form usable as the input of computer model. First of all the frequency distribution of wind at any point (grid square) of the surveyed area must be known; this, however, on areas being influenced by physiographic factors can not be determined by interpolation from even the data provided by stations very close to each other. The only way to solve the problem seems to be creating a *typology of surface wind patterns.* Knowing the frequency of the different types, *the frequency of the individual wind courses* in the usual division of 16 directions *could be given for any point of the area under survey.*

2.2. For regions being under orographic influence the frequent – though to a certain extent regular and classifiable – spatial change of airflow is characteristic. Wind fields must be classified into more or less steady-state types with *trajectories, representing those lines along which dispersion of the pollutions originated from surface or regional sources is taking place with a definite frequency.*

2.3. The mass of data used for the preparation of present study was limited – because of the great time requirements of the work – to a period of one year. However, the frequency of wind courses can differ a great deal in individual years from the average climatically characteristic to a long period of time. It is obvious that conditions *to gain appropriate, climatologically valid data about the types of wind fields* and about wind course frequencies had to be created. In order to solve the problem, Pestlőrinc Observatory, having a long range of data, has been included in the classifying of wind fields. We established the relation of the individual types with the wind courses occurring in Pestlőrinc. The procedure – in our opinion – can be successfully applied in the quite frequent case when for the preparation of a decision of regional planning or industrial location, the wind climate of the regions considered must be characterized by field measurements of not more than one year while anemograph data of a long series are available at a distance from the spot only.

3. *The types of surface wind fields in Budapest*

3.1. *The process of classification*

The basis for the classification of surface wind fields was provided in form of maps by the Air Quality Department of Central Institute for Physics of Atmosphere. Each map represented a certain hour of the year 1969. The data put on the map originated from the following wind registering stations: Pestlőrinc Observatory, Kitaibel Pál Street, Szabadság-Hill Astronomical Observatory, Citadel on Gellért Hill, Budaörs Airport, Óbuda, Madách Square, Zoo, Gyáli Street (Institute for Public Hygiene). The data coming from the network of 9 anemographs were completed by the wind-vane data of the climate stations of Rákospalota and Nagytétény in the hours of observations (Figure 1.).

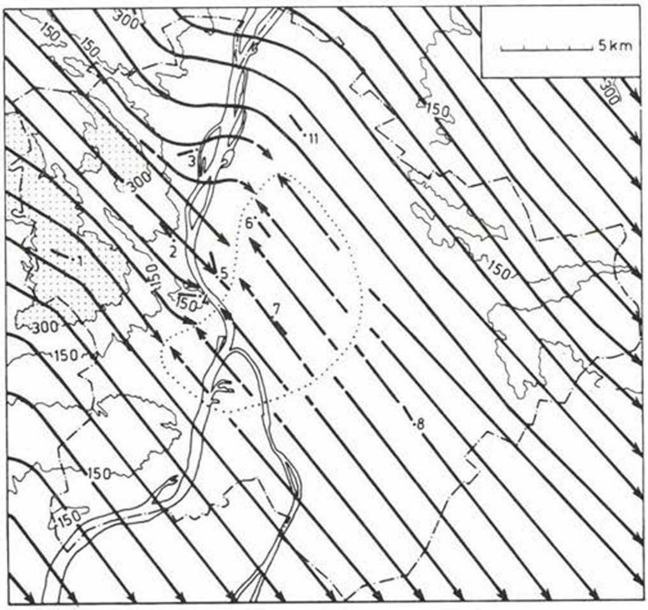


Fig. 1. The anemograph station network used for the purpose of this study. – The surface wind field of this seldom occurring type is due to the heat island effect.
1=Szabadsághegy, 2=Kitaibel Pál Street, 3=Óbuda, 4=Gellérthegy, 5=Madách Square, 6=Állatkert (Zoo), 7=Gyáli Street, 8=Pestlőrinc, 11=Rákospalota. The stations of Budaörs and Nagytétény in the SW of the city do not appear on the map. The dotted area represents the highest part of the Buda Hills.

The approximately 8700 map sheets were systematically arranged according to the wind courses registered first of all at Pestlőrinc. It seemed expedient to choose this observatory with a long range of data as the basis of classification, because presumably this observatory ensures relatively the best representation of undisturbed large-scale airflow pattern within the boundaries of the capital. Further on we drew the wind field characteristic for each hour on the sheets. During the process we mainly depended on the wind-vanes of the stations with attempts to take the orographic relations into consideration. The next step was to classify the rough types by selecting the most frequently occurring airflow patterns. Then we assorted the whole series of maps in a way that the actual wind fields of the maps should show the closest possible similarity to the type they were ordered to. The similarity between the real and the typical wind fields has been controlled on a sample containing 16 per cent of the entire material (the map sheets of February and August). The results obtained have been utilized in shaping by some corrections the best fitting final types of airflow patterns.

3.2. The representativity of the types of wind fields

As the final stage of the work, based on parallel wind observations – a so to say microsinoptic method – 36 different types of the wind fields in Budapest have been established (see maps in the appendix). Into these types 91 per cent of the hours of 1969 could be classified. The ratio of the non-classifiable hours were almost the same both in the winter and summer half years (October – March 9,4%; April – September 8,6%). The wind field is more or less irregular and therefore non-classifiable in case of a front passing through the capital. Another fraction of the non-classifiable cases belong to weather types without any large scale airflow; this category included all the calm hours in Pestlőrinc. The proportion of the non-classifiable cases according to the "macro-scale" wind direction in Pestlőrinc can be obtained from *table 1:* it is the lowest when N and NNW winds prevail (3,7 and 3,4 per cent of the hours), while it is the highest in the category of WSW and SW winds (16,5 and 16,0 per cent respectively).

The proportion of the non-classifiable cases could have been reduced by increasing the number of types in the classification, but, as a result, the practical usability of the method would be decreased. Therefore, the repetitious cases, showing similar wind field were not regarded as separate types, if their frequency of occurrence did not surpass 0,5%. Neither seemed it desirable to hold down the proportion of the non-classifiable cases by allowing the range of scatter of the wind directions to widen within the categories.

The mean wind directions characteristic for the different types observed at the stations are included in table 2. Generally, the mean wind direction represents the most frequent wind direction within the category of a given type. In those cases, where according to the witness of the 16 per cent sample a wind direction different from the mean appears to be more frequent, this wind direction is then also included in the table.

The real wind directions disperse around the wind direction denoted by the given type for the individual stations. It is a question of high importance how accurately the types reflect the real wind direction of the given hour, with a special regard to the possibility of committing mistakes during the process of classification. The comparison of the real and the clas-

Relative frequency of the non-classifiable cases
(in percent of the total number of

N	NNW	NW	WNW	W	WSW	SW	SSW	S
3,7	3,4	7,2	14,4	9,4	16,5	16,0	10,5	12,0

sified wind field was carried out by using the map sheets of the months February and August, for 7 stations (Szabadság Hill, Kitaibel Pál Street, Óbuda, Gellért Hill, Madách Square, Gyáli Street and Pestlőrinc). As evident from the sample the divergence between *the real and the "typical" wind direction surpasses an angle of ±22,5 degree only in 13,6 per cent of the cases.* Naturally, this figure changes from place to place and from type to type (see table 3). The wind directions least fitting into the frame of types are those of Óbuda, a station being strongly influenced by the Hármashatár Hill and the Solymár Valley. The strongest divergence of the real and "typical" wind courses can be experienced in the types characterized by light wind and consequently by strong local influences (table 4).

3.3. The frequency of occurrence of the wind field types

The frequency of the occurrence of the wind field types ranges within fairly broad limits. The question rises how the probability (P) of occurrence of the types on the long run can be conducted on the basis of the frequencies (F) determined from the material of one single year. The difference of F and P can be attributed to two factors: *a)* the frequency distribution of large-scale wind directions of the examined year may differ from the climatological average distribution; *b)* the occurence of the wind field types within those hours characterized by a given macro-scale wind direction may not coincide with the average of a long period.

Since the number of wind field types occurring within the frame of a certain macro-scale wind direction is not high, and their frequency or proportion of occurrence must be mostly determined by the constant orographic factor, it can be assumed, that at high aggregational level of data, e.g. when examining yearly frequencies and the ones for 6 months, the *a)* source of error is more significant. This type of error can be eliminated by utilizing the series of data provided by a reference station with long observation period (Pestlőrinc Observatory).

First of all the frequency distribution of wind fields belonging to the wind direction has been determined for the whole year of 1969, as well as for the winter and summer half year. On this basis the approximative climatological probability of occurrence of a certain type can be given in the following way:

$$P = \sum_{i=1}^{16} P_i f_i$$

Table 1.

according to macro-scale wind directions (1969)
hours of the given wind direction)

SSE	SE	ESE	E	ENE	NE	NNE	Total sample
10,1	12,8	7,9	6,6	6,9	9,3	6,8	9,0

where f_i is the frequency of the occurrence of the type related to the total number of hours with prevailing large-scale wind direction i; whereas P_i represents the probability of occurrence of the i wind direction according to a long series of observations.

The wind course frequency distribution in Pestlőrinc for the year 1969 can be compared with the average frequency for the decade between 1968 and 1977 (table 5), determined from the data published in the yearbooks of OMSZ (National Meteorological Service). The latter data derive from observations in every third hour. The annual and seasonal probability of occurrence of the wind field types in Budapest, calculated with the above mentioned method, are listed on the figures in the appendix.

The highest probability (13,1 per cent of all the hours) is exhibited by type 1; in case of large-scale NW and NNW winds this is the most frequent situation. The divergence arising in North-Pest as a result of the effect of Hármashatár Hill on the surface wind field is a prominent feature of this type and supposedly is also characteristic to several other westerly-directed types of smaller probability (types 2, 3 and 4), a fact being obviously correlated with the spatial minimum of precipitation in the region of North-Pest (Berkes, 1947, Bacsó, 1958, Probáld, 1974).

Very high is the probability of occurrence of wind field type 15 (9,2 per cent), connected to large-scale SE and ESE winds; that of type 17 (7,3 per cent), characterized by easterlies and a slight divergence caused by the Buda Hills; and of type 35 (5,2 per cent), being in most cases linked with N winds.

3.4. Local circulations as reflected in the types of wind fields

Among the types of the surface wind fields relatively small is the frequency of those being strongly influenced by local factors – mountain and valley breeze or urban circulation. The urban circulation elicited by the urban heat island exhibits airflow pattern converging towards the centre of densely built-up areas. But, in the case of Budapest, the modifying effect of the orography and the mountain and valley breeze make it rather difficult to give an evidence for this much-discussed urban circulation.

Péczely (1962) regarded the emergence of urban circulation for being proved for those hours, when in Buda (Kitaibel Pál Street), a wind from the WSW-NNW sector prevails, at the same time, however, an ESE-SSE flow could be observed in Pestlőrinc. From the above determined types of the

Table 2.

Mean wind direction at Budapest stations in the different types of wind field
(on the second place the modal direction is listed if different from the mean one)

Type number/Station	1	2	3	4	5	6	7	8	9	10	11	12
Szabadsághegy	WNW	W	WSW	WSW	SW	SW	SSW	SW	S	SW	SSW	SE
	NW						S				S	
Óbuda	WSW	SW	SW	SSW	SSW	SSE	S	SW	SE	SSW	SE	ESE
	SW				S				SSE	S		
Kítaibel P. u.	NW	NW	WNW	NW	WSW	WSW	WSW	W	SSW	WSW	SW	SSW
									SW			
Gellérthegy	NNW	NW	WNW	WSW	SW	SW	SSW	W	S	WSW	S	SSE
									SSE			
Madách tér	NNW	NW	WNW	SW	SW	SW	SSW	W	S	SSW	S	S
Gyáli út	NW	NW	W	WSW	WSW	SW	SW	SW	SSW	SSW	SW	S
			WSW	W						SW		SSE
Pestlőrinc	NW	WNW	W	W	WSW	WSW	WSW	SSW	SSW	S	S	S
		NW					SW	SW	S	SSW		
Állatkert	NNW	NW	WNW	WNW	WNW	SSW	S	NW	SSE	S	SW	SSW
		NNW			W							
Budaörs	WNW	W	WSW	WSW	WSW	SW	S	SW	SSE	SSW	SSW	SE
	NW										S	

Type number/Station	13	14	15	16	17	18	19	20	21	22	23	24
Szabadsághegy	SSW	ESE	SW	SSE S	E	NE	NW	NE	NE	NE	NE	NE
Óbuda	SW	ENE NE	S	ESE	NE	SW	WSW	NNW	WNW	WSW	WSW SW	W WSW
Kitaibel P.u.	W	SE	SSW	S	E	NW	NW	ENE	NE	NNE N	N	NE
Gellérthegy	NNW	SE	S	S	ESE	N	NNW	NE NNE	N	N	N	N
Madách tér	N	SE	S	SSE	E	NNE	NNW NW	ENE	NE	NNE	NNE	NNE
Gyáli út	S	SE	SW	S	ESE	NE	NNE	E	ENE	NE ENE	NE NNE	NE NNE
Pestlőrinc	SSE SE	ESE	SE	SE	E	ESE	ENE NE	E	ENE E	ENE E	ENE	NE
Állatkert	NNW	SE	SSW	SSE	SE	NE	NNW	E	NE	NNW	NNE	N
Budaörs	SSW	ESE	SSW	SSW	E	ENE	NNE	NE	NE	NNE	NE	NNE

Table 2. continued

Type number/Statiou	25	26	27	28	29	30	31	32	33	34	35	36
Szabadsághegy	NE	ENE	ENE	NNE N	NNE	NE ENE	NNW N	NW	N	N	NW	W
Óbuda	WNW NW	W	NW	NW	SW	WSW SW	NW	WSW	WSW	WSW SW	WSW	SW
Kitaibel P. u.	NE	ENE	NE	NNE	NW	NE	E	NNW NW	NW	NE	NW	WNW NW
Gellérthegy	NE NNE	ESE	N	N	N	N	N	N NNW	NNW	NNW N	NNW	NW
Madách tér	NE	E	NE	NNE	N	NNE	N	N	NNW NW	NNE	NNW	WNW
Gyáli út	NE	ENE	ENE	NNE	NNE	NNE	NNE	NNW	N	NNE	NNE	WNW W
Pestlőrinc	NE ENE	NE ENE	NE	NNE	NNE	N	N	N NNW	N NNW	N	NNW	NNW NW
Állatkert	NE	ESE	NNW	NNW	N	NNE	NNW	NNW	N	N	NNW	WNW
Budaörs	NE	ENE	ENE	N	NNE	ENE	NW	WNW	N	N	WSW	W

surface wind field types 13 and 18 correspond to the criteria adopted by Péczely, with the cumulative probability of their occurrence (3,5 per cent) being roughly the same as the figure given in his paper. The summer peak also underlines the reality of Péczely's calculations. Since the urban heat island developes the most strongly in the evening, the urban circulation can be strengthened by the flow of cold air through the Buda valleys and slopes, that is by night effect of mountain and valley breeze. The map of the more frequent type 13 shows the determining role of the urban circulation, while the less frequent type 18 is likely to be dominated by the mountain and valley breeze.

There are several other types besides the two above mentioned, where the map of wind fields shows definite convergence above the city. In most of the cases this convergence is the result of the modifying and diverting effect of the Buda Hills (types 4, 8 and 10). However, it is noteworthy, that in the case of ENE and NE macro-scale winds the strong convergence pointing to the city centre is also frequent (types 19 and 23). These stream-field types are mostly due to the night branch of the mountain and valley breeze, since they occur quite regularly during summer nights, with the breeze being also supported by the urban heat island. The strong divergence that shapes itself along the peak region of the Buda Hills without the significant convergence to be experienced in the centre of the city, is unambiguously a result of the downward flow of cold air during the night (types 29 and 33).

It is remarkable, however, that there is no single circulation type where either the daytime branch of the valley and mountain breeze or the urban circulation could assert itself against macro-scale winds blowing from the NW sector. Among our original, preliminary types there was one, where in spite of the NW winds of the Buda stations and Pestlőrinc, in a strip encircling the city core on the eastern side airflow towards the centre could be registered (fig. 1). This type of airflow pattern occurring mostly in summer clearly reflects the effect of the city heat island, but because of the low rate of its occurrence (only 0,34 per cent of all the hours) and the strong fluctuation of the wind courses belonging to it, we did not regard it as worth counting among the final types, consequently it has been included into the non-classifiable cases.

On the basis of the wind-field typology, the following statements can be made about the local air circulation:

a) Several stream-field types can be separated where the impact of the local circulations can be observed. Their collective probability of occurrence amounts to 11 per cent of all hours, and they occur most frequently during summer nights.

b) In the above mentioned position types, the joint effect of the night branch of the mountain and valley breeze and the urban heat island is reflected. In the case of the airflow converging towards the centre during the day – the predominant role of the urban heat island effect becomes obvious. More frequently the cold air flowing down along the valleys modifies the pattern of circulation.

Frequency distribution of the difference (Δx) between the real and

Type number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
$\lvert\Delta x\rvert \leq 22{,}5°$ ...	92	88	87	86	92	87	83	71	91	75	80	88	54	85	87	84	85	61
$\lvert\Delta x\rvert > 22{,}5°$ ...	6	8	9	11	7	8	7	18	7	18	13	9	19	11	4	7	10	15
$\lvert\Delta x\rvert > 45°$	2	4	4	3	1	5	10	11	2	7	7	3	27	4	9	9	5	24

c) The daytime branch of the mountain and valley breeze, partially set off also by the heat island circulation, can almost never develop against the generally strong winds blowing from the NW sector. Rarely though, but there is evidence that the urban circulation takes shape on smaller or larger areas even in weather types with prevailing north-westerlies.

d) The situations displaying the characteristics of local circulations can be described as having weak, uncertain air motions, therefore their classification is rather difficult, which is also reflected in the relatively strong scattering of their wind courses (table 4.).

3.5. The frequency distribution of wind courses according to the stream-field typology

Through knowing the probability of occurrence of the different types of surface wind fields, it becomes possible to estimate the frequency distribution of the wind courses on the area under discussion – in this case Budapest –, to any point or grid square of it. The method is based on the great similarity of the real wind courses and the ones denoted by the given type (table 3). As it has been mentioned above, the real wind courses disperse in a relatively narrow interval around the average wind course that can be spotted from the map of any occurring type. The normality of the distribution of wind directions has been checked by the χ^2 test. According to the entire material, the variance of the real wind courses around the type wind direction can be approximated by a normal distribution of parametres $M = 0$, $\sigma = 20°$ (σ was estimated on the basis of the empiric frequencies belonging to the $\pm 11{,}25°$ interval limits). The functions of the normal distribution characterized by the above parametres – as well as the empiric frequencies are given in table 8.

Taking advantage of the theoretical distribution, the actual distribution of wind directions can be given to any angle of airflow, read from the map of the type. If the degree taken from the map differs from the main wind direction by x, then the function values of a normal distribution with a mean value of $M = x$ instead of $M = 0$, are serving as a basis to determine the real wind course distribution. Since the accuracy of reading off the type wind course is limited, practically at most the distribution belonging to $x = 11{,}25°$, representing the middle strip ($5{,}6° - 11{,}8°$) of the interval of two main wind courses, e. g. N and NNE can be regarded as necessary to be used on occassions (table 6). For the sake of simplicity, the extreme

Table 3.

the type-indicated wind directions in percent (average of 7 stations)

Type number	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
$\|\Delta x\| \leq 22{,}5°$ ..	71	93	87	90	81	85	84	91	80	90	91	84	82	87	91	89	89	93
$\|\Delta x\| > 22{,}5°$ ..	16	4	8	9	11	13	14	9	12	10	6	11	8	10	7	10	9	7
$\|\Delta x\| > 45°$	13	3	5	1	8	2	2	0	8	0	3	5	10	3	2	1	2	0

categories of the distribution can be practically disregarded. It seems to be sufficient to apply a division rounded off to 30 – 40 – 30 per cent and 10 – 40 – 50 per cent, and this way to divide the total probability share of any type among three major wind directions.

Reading off the wind courses with an accuracy of $\pm 11{,}25°$ only, the real probability of occurrence (P_x) of any x wind direction at a H place can be given as follows:

$$P_x = 0{,}4\ \Sigma\ P_j + 0{,}3\ \Sigma\ P_i + 0{,}3\ \Sigma P_k$$

where P_j is the summed probability of occurrence of those types with X mean wind direction belonging to H place; while P_i denotes the probability types indicating a wind direction of $X - 22{,}5°$, and P_k. the probability of those indicating wind direction of $X + 22{,}5°$, respectively.

Table 4.

Frequency distribution of the difference (Δx) between the real and the type-indicated wind directions in percent (average of 36 types)

Station:	Szabadsághegy	Óbuda	Kitaibel P. u.	Gellérthegy	Madách-tér	Gyáli -út	Pestlőrinc	Mean value
$\|\Delta x\| \leq 22{,}5°$	81,4	74,8	84,8	87,1	92,1	86,6	97,6	86,4
$\|\Delta x\| > 22{,}5°$	12,8	13,8	11,0	8,1	6,4	10,2	2,4	9,2
$\|\Delta x\| > 45°$	5,8	11,4	4,2	4,8	1,5	3,2	–	4,4

Table 5.

Relative frequency of wind directions in Pestlőrinc (in percent, disregarding calm hours)

A: 1969 B: 1968 – 1977

	N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	E	ENE	NE	NNE	$\Sigma\|\Delta\|$
A	7	10	9	5	4	4	4	3	5	4	6	10	11	6	6	6	–
B	8	11	9	5	5	4	4	4	6	5	7	9	9	4	5	5	–
$\|\Delta\|$	1	1	–	–	1	–	–	1	1	1	1	1	2	2	1	1	14

Table 6.

Frequency distribution of the difference between the type-indicated and the real wind direction (%)

Intervals of difference	Empirical values	Normal distribution ($\sigma = 20°$, M = O)	Practically applied distribution for M=O	Normal distribution ($\sigma = 20°$, M= 11,25°)	Practically applied distribution for M= 11,25°
$\Delta <\ -33{,}75°$	6,8	4,6	–	1,4	–
$-33{,}75 - 11{,}25°$	21,5	24,1	30	11,8	10
$-11{,}25 - 11{,}25°$	43,4	42,6	40	36,9	40
$11{,}25° - 33{,}75°$	21,5	24,1	30	36,9	50
$\Delta >\ 33{,}75°$ ..	6,8	4,6	–	13,0	–

Table 7.

Frequency distribution of wind directions (February and August 1969)

A = calculated values, B = real values

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	WSW	WSW	W	WNW	NW	NNW	Σ
Madách tér A ...	15	11	9	7	6	6	4	5	5	4	2	1	2	2	9	12	100
B ...	12	14	11	4	6	6	4	4	7	3	2	1	2	4	9	11	100
(Δ) AB ...	3	3	2	3	–	–	–	1	2	1	–	–	–	2	–	1	18
Gellérthegy A ...	20	6	2	2	3	4	6	5	6	4	3	2	2	3	12	20	100
B ...	19	10	2	2	3	7	7	5	4	4	2	2	1	2	10	20	100
(Δ) AB ...	1	4	–	–	–	3	1	–	2	–	1	–	1	1	2	–	16
Madách tér – Gellérthegy (Δ) B ...	7	4	9	2	3	1	3	1	3	1	–	1	1	2	1	9	48

Table 8.

Frequency distribution of wind directions at Pestlőrinc (1968 – 1977) without calm hours;
A = calculated values, B = real values

	N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	E	ENE	NE	NNE	Σ
A	8	10	8	7	5	4	3	4	5	5	6	9	9	6	5	6	100
B	8	11	9	5	5	4	4	4	6	5	7	9	9	4	5	5	100
$\lvert\Delta\rvert$	–	1	1	2	–	–	1	–	1	–	1	–	–	2	–	1	10

The above detailed method enables to estimate the frequency distribution of winds for areas under orographic influence more precisely than it could be done by extrapolating the data of any nearby station. To prove this, we present the distribution of wind directions determined from anemograph registrates, as well as from the type frequencies for Madách Square and Gellért Hill, for the two months (February and August 1969) analysed in the control sample. These two stations were selected because though they are only at 1,4 air-kilometre distance from each other, there is more than 110 metres difference between the altitude of the two places. The very different orographic conditions lead to wind frequencies strongly divergent from each other. According to table 7, there is 16 per cent difference between the calculated and the real wind course distribution on Gellért Hill, and 18 per cent on Madách Square, compared to the 48 per cent difference that could be resulted from the method of extrapolation. However, it is noteworthy, that because of the fault of the anemograph, the wind course data were missing from 9 per cent of all hours on Gellért Hill and from 8 per cent of all hours on Madách Square, while the distribution of types was only given for the full months; therefore the inaccuracy of the wind course distribution accepted to be "real" may distort the result.

For the further checking of the method elaborated to determine the wind course frequencies, on the basis of the type wind courses and the known probability of the types' appearance we determined the frequency distribution of winds for Pestlőrinc, and then we compared it with the real distribution for the 1968–1977 years established from data of the yearbooks of the National Meteorological Service (table 8). The 10 per cent difference between the distributions calculated in two different ways, is less than that between data gained for the same station from a certain year and from a whole decade (table 5). This is a quite convincing illustration to the usefulness of the method. The material of the tables 2 and the data published in the appendix maps allows us to calculate the wind frequency distribution for any station in Budapest for the decade 1968–1977, and by applying the attached maps of types and the figures of type frequency, the process can be carried out, if needed, to any point of the capital.

4. The effect of the city on wind speed

Parallel with the elaboration of the method for the calculation of wind frequencies we also examined the essential problem, how the wind speed changes on the territory of the capital. It is well known from the studies of Bán and Gajzágó (1974), that the *average* wind speed is 3 per cent less in Gyáli Street (Institute for Public Hygiene) and 16 per cent less on Madách Square than in Pestlőrinc. According to the authors of the study, this decrease is mostly due to the effect of the Buda Hills. Furthermore, in the above mentioned study of Bán and Gajzágó the first attempt to examine the differences of wind speed between Madách Square and Pestlőrinc in a breakdown according to directions was also carried out.

However, it is obvious, that the decrease of wind speed in the centre of the city must also depend on the basic wind speed observed above natural surfaces. To determine the extent of the effect the data of anemographs from January and July 1968, have been examined, and in the case of high wind speeds – where it was necessary – further two months of winter and summer have also been involved in the survey. The speed data of Gyáli Street and Madách Square have been divided into 8 groups, according to the wind direction registered at Pestlőrinc. The grouping was done in a way that the secondary wind courses were joined to the main wind couress counterclockwise. The second step was to classify the figures belonging to each wind direction into intervals of 0,5 m/s, on the basis of the speed experienced at Pestlőrinc. Subsequently, for each group the mean values of wind speed have been calculated for the stations Madách Square and Gyáli Street. On the modification of the wind speeds the following summary statements can be made:

a) Above the surface of the built-up areas of the city the slow streams are not weakened but strengthened. The weakening effect of the city, depending on the course of the wind, only starts to dominate after surpassing the critical value of 1,5–3,5 m/s.

This phenomenon was also experienced in some other cities. In his work on the climate of London, Chandler (1965) gives the following explanation: weak currents over natural surfaces are combined with insignificant turbulent mixing, whereas the increased mechanical turbulence over the city is combined with stronger exchange of momentum, therefore it results in the increase of windspeed near the surface. In the case of stronger winds, on the contrary, the role of the friction caused by the rougher city surface becomes dominant. In our opinion, it must be added to Chandler's reasoning that the roof level of the city, that is the basis for the anemographs, from the point of view of the airflow is not totally equivalent with the ground level, and the airflows going on in the space of the streets also can have a role in the more vivid airflows occurring above roof level in nearly calm weather.

b) The speed of the N, NW and NE winds decreases only slightly above the city as compared to that of Pestlőrinc. Besides the stronger turbulence of these winds, this fact may be due – at least in the case of N and NW winds – to the Pestlőrinc observatory being also effected by the city. The strongest decrease in wind speed is characteristic for the E wind direction.

c) The probably slight daily and seasonal differences in the decrease of wind speed could not be demonstrated from the realtively small sample.

From the point of view of wind speeds Madách Square can be regarded as characteristic to the centre of the city, while Gyáli Street represents the transitional area around the city core. The mean wind speeds belonging to the different wind directions registered at Pestlőrinc have already been published (Bán and Gajzágó 1974). Thus, it has been rendered possible to determine the mean speed belonging to any wind direction – an essential figure from the point of view of the conditions of transmission – for practically any point of the flat Pest side of the Hungarian capital.

*

The author wishes to express his thanks to the members of the Air Quality Research Department of the Central Institute for Physics of Atmosphere, who inspired and made it possible to carry out the research summarized in this paper.

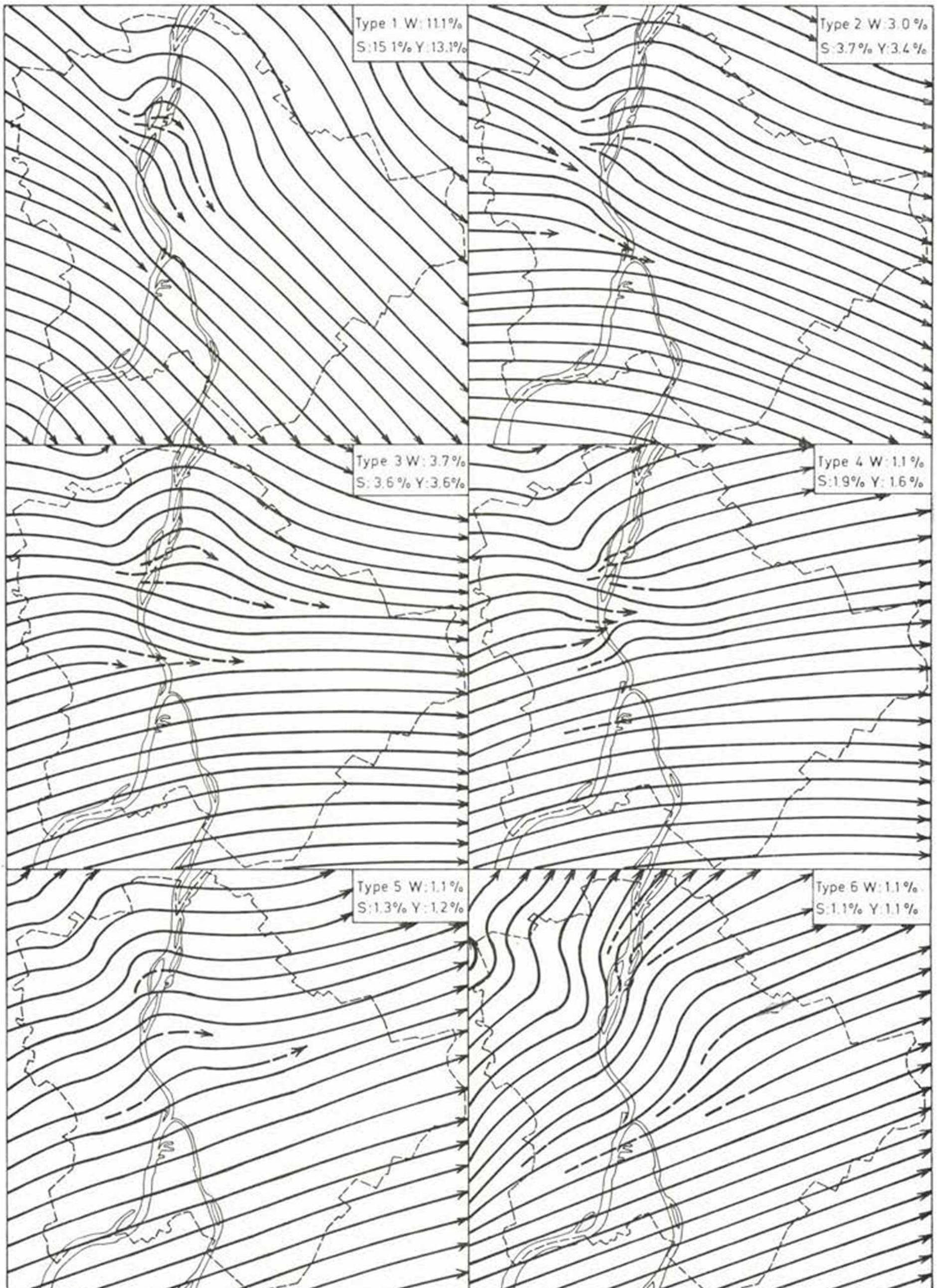
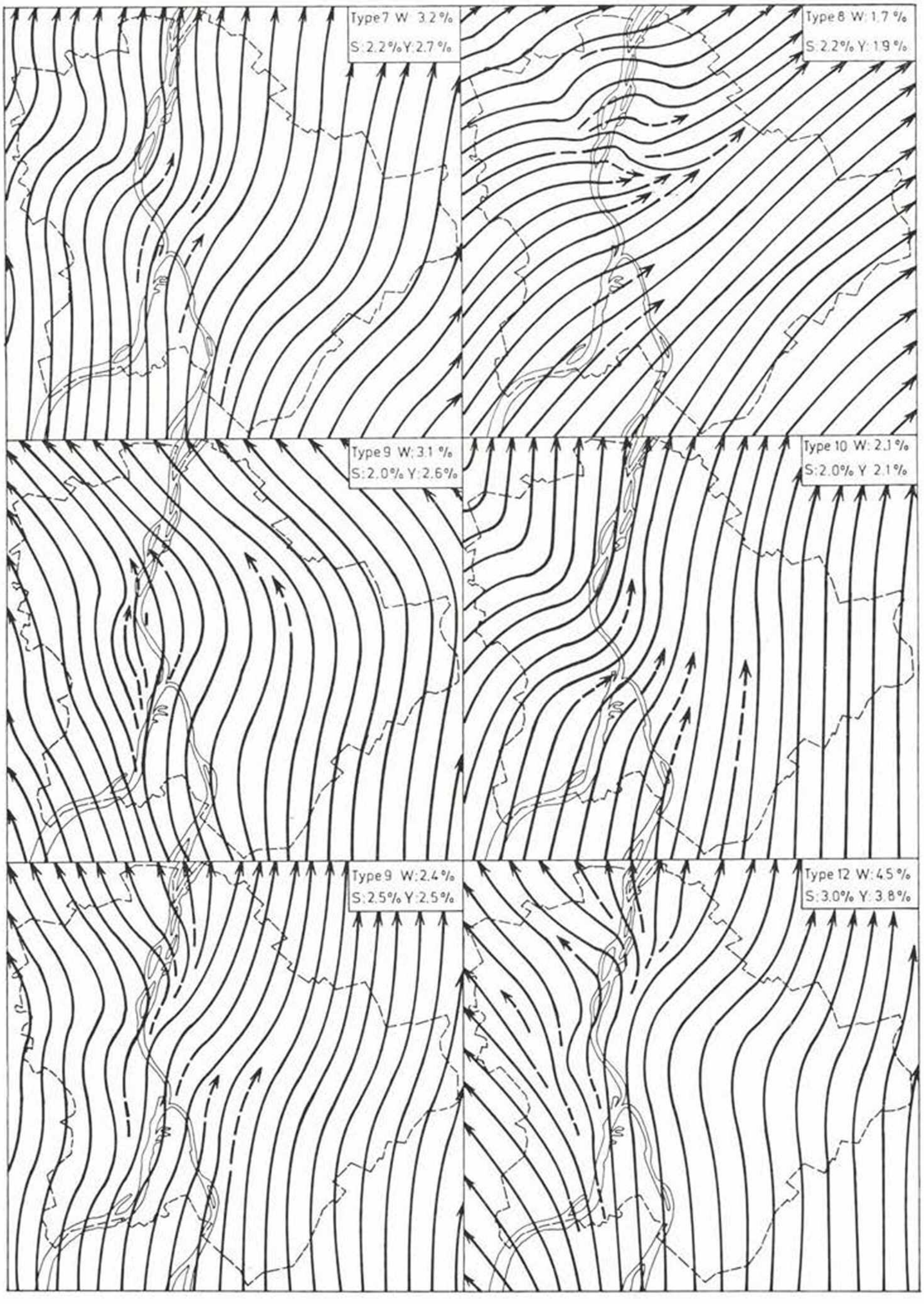


Fig. 2 – 7. Types of surface wind field and frequency of their occurrence in per cent of the total hour intervals. W = winter halfyear, S = summer halfyear, Y = year.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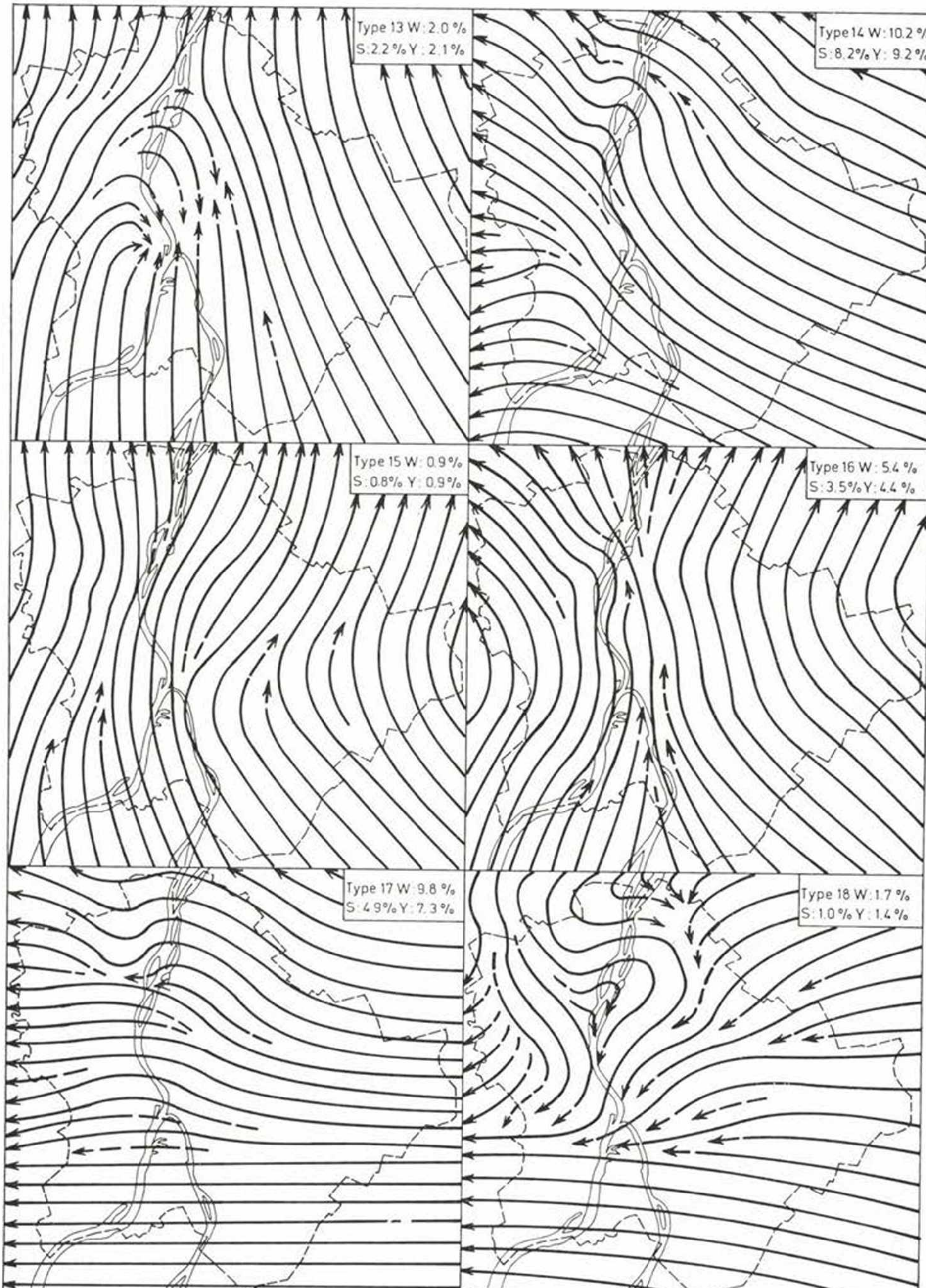
S: 2.2 % Y: 2.7 %
Type 8 W: 1.7 %
S: 2.2 % Y: 1.9 %
Type 9 W: 3.1 %
S: 2.0 % Y: 2.6 %
Type 10 W: 2.1 %
S: 2.0 % Y: 2.1 %
Type 9 W: 2.4 %
S: 2.5 % Y: 2.5 %
Type 12 W: 4.5 %
S: 3.0 % Y: 3.8 %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S: 2.2 % Y: 2.1 %
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S: 8.2% Y: 9.2 %
Type 15 W: 0.9 %
S: 0.8% Y: 0.9 %
Type 16 W: 5.4 %
S: 3.5% Y: 4.4 %
Type 17 W: 9.8 %
S: 4.9% Y: 7.3 %
Type 18 W: 1.7 %
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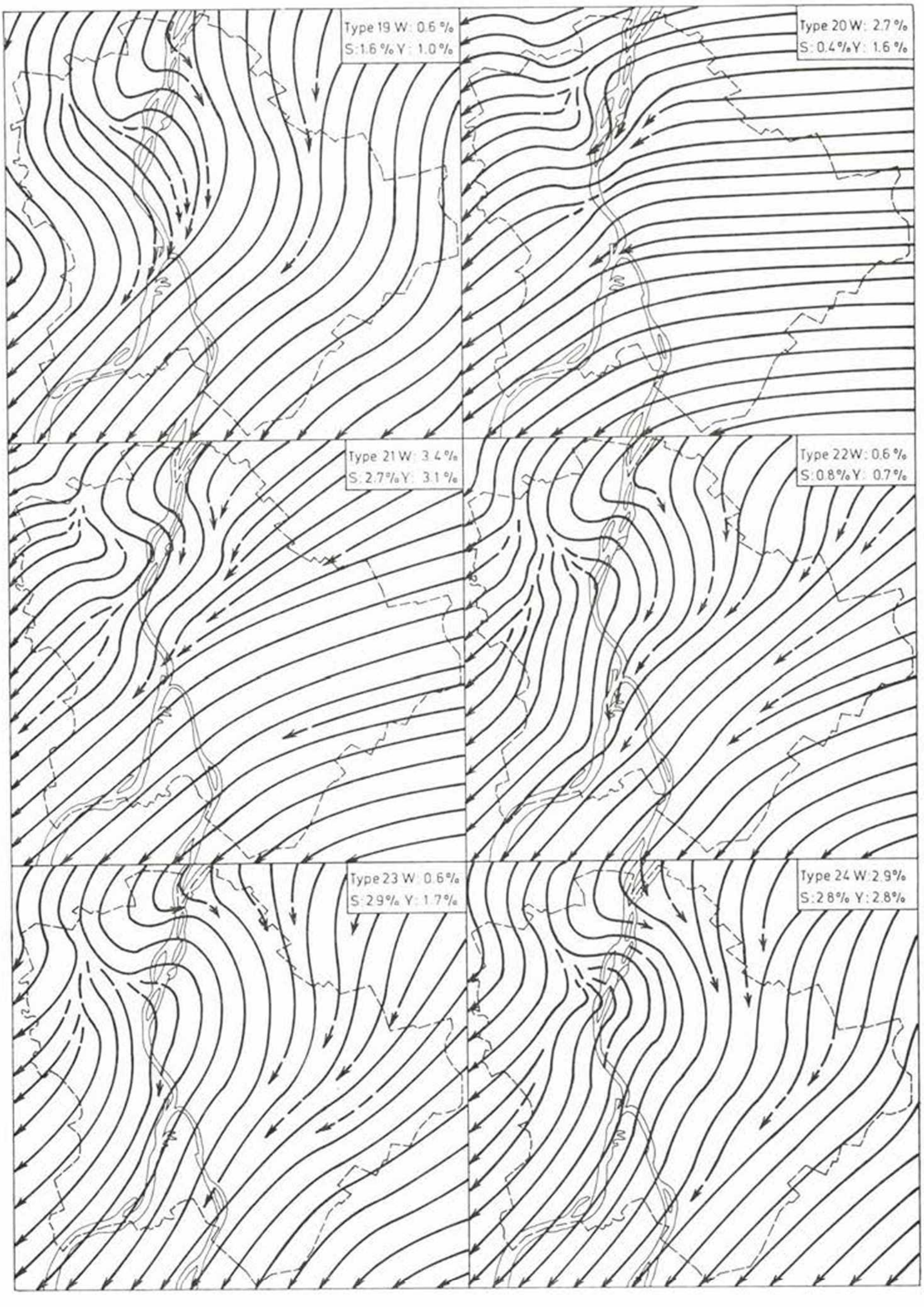
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S: 0.4 % Y: 1.6 %
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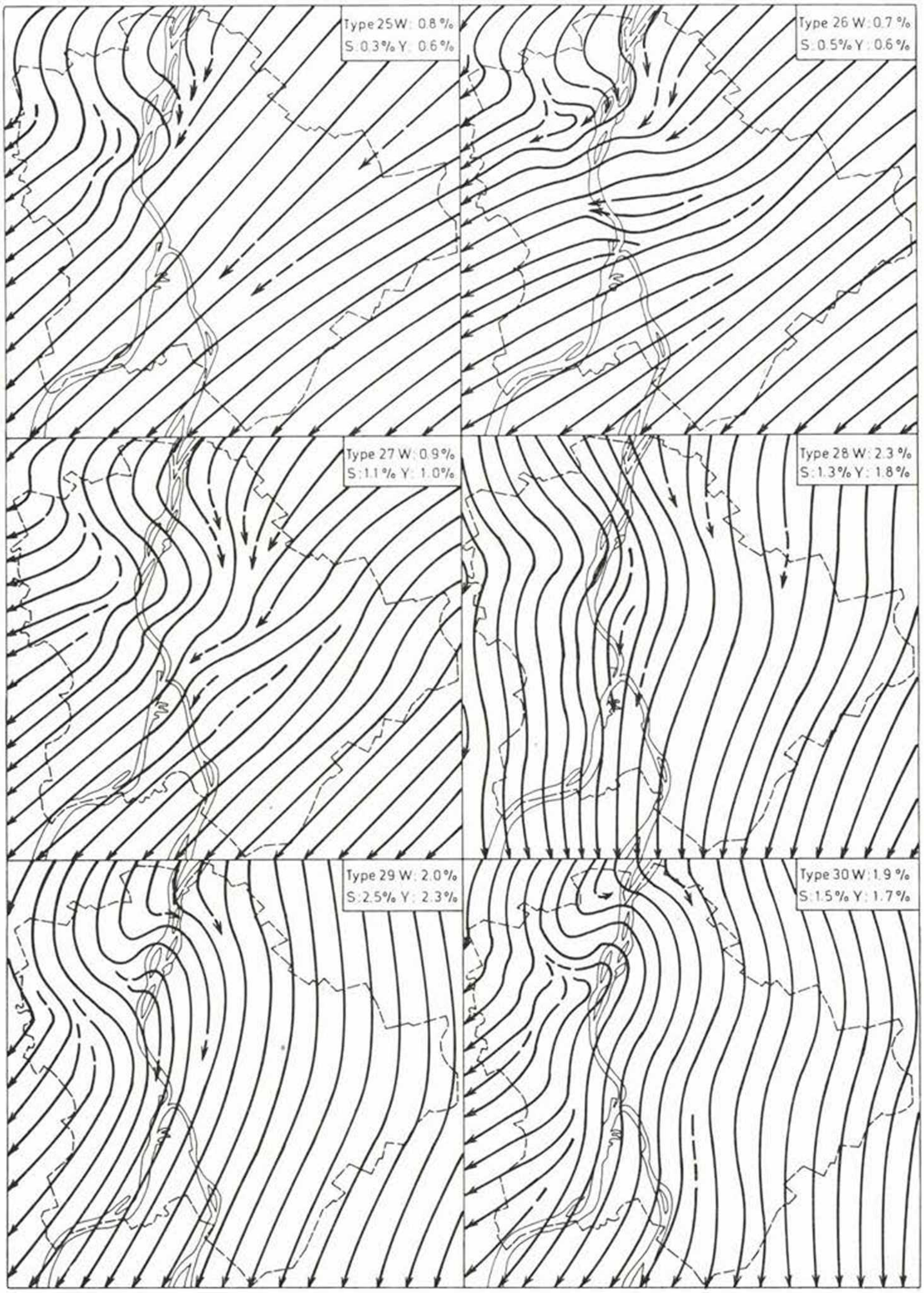
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Type 28 W: 2.3 %
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Type 29 W: 2.0 %
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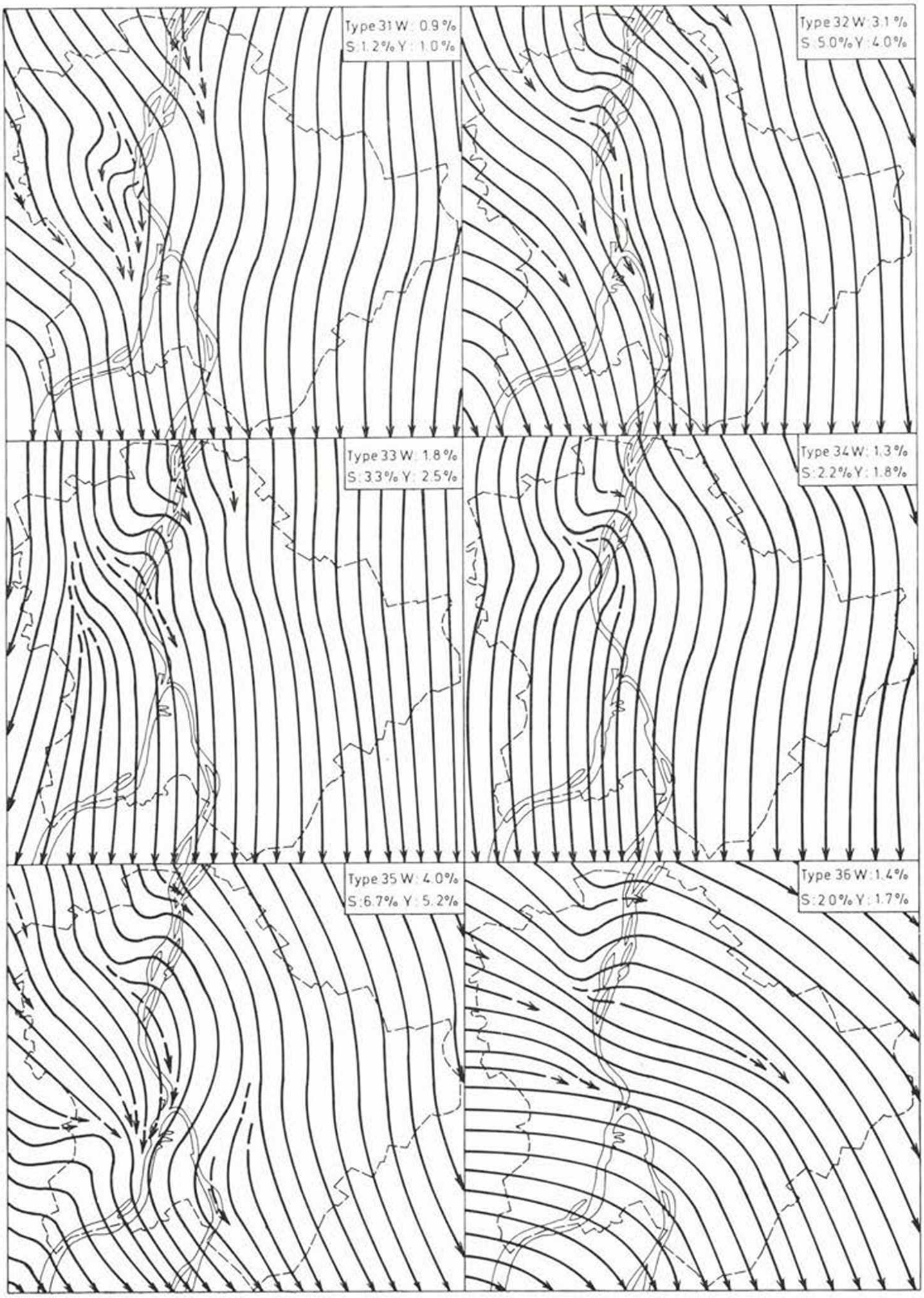
Type 30 W: 1.9 %
S: 1.5 % Y: 1.7 %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РЕЗЮМЕ

ТИПЫ ПРИЗЕМНОГО ПОЛЯ ТЕЧЕНИЙ В БУДАПЕШТЕ

В ветровом климате Будапешта отмечаются территориальные различия в зависимости от рельефа и застройки. Автор обработал данные 9-ти ветромеров города за 1969 год, на основании которых были составлены почасовые карты для определения микросиноптических типов приземного поля течений.

Картина течений в ряде типов ясно отражает как городскую, так и горно-долинную циркуляцию.

Знание частоты повторяемости 36 выделенных типов дает возможность определить распределение частоты направления ветра, относящееся к любой точке или квадрату сетки города, которое имеет значение для мероприятий, направленных на защиту воздушной среды. Применение метода типизации может быть эффективным и в диффузионно-климатологическом описании территорий, находящихся под влиянием рельефа.